



Analysis and case studies of residential heat metering and energy-efficiency retrofits in China's northern heating region



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ABSTRACT

During the past 5 years, the Chinese government has organized and implemented a large-scale energy-efficiency retrofit program for existing residential buildings in China's northern heating region. However, many obstacles, especially lack of successful financing arrangements, have limited the implementation of retrofits under the program. This paper analyzes the key financing challenges that have faced the program, using case studies of the different financing arrangements that have been used. Some of the key issues influencing the program's success to date are differing retrofit and other priorities of various stakeholders, timing and methods of payback on investments, potential investors' lack of access to risk analysis, uncertainty about benefit sharing, and the need for revisions in policies governing retrofits and energy contracts. We make recommendations to address these issues and improve the success of the north China energy-efficiency retrofit program.

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1. Introduction

Energy for heating accounts for the largest share, 35.7% of energy consumption in buildings in China's northern towns. In 2008, heating energy represented 23% of total building energy consumption in China [6]. The total floor area in China's northern heating region was 8.8 billion square meters (m^2) in 2008 [7], of which more than 70% was in high-heating-energy consuming buildings that used more than 25 kg of coal equivalent (kgce/m^2) per year [19]. In 2008, the total heating energy consumption in China's northern towns was 1.53×10^8 t of coal equivalent (tce), and the average energy consumption for heating was $17.4 \text{ kgce}/\text{m}^2$ [7]. It was estimated that 6.8×10^7 tce would be saved and 1.43×10^8 t carbon dioxide (CO_2) emissions would be reduced per year if the national energy-efficiency design standard for heating in new residential buildings was applied in energy-efficiency retrofits in China's northern heating region [20].

Although older residential buildings in northern China consume a significant amount of energy for heating, the maximum indoor temperature during the heating season is only 14–16 °C because of poor heating system efficiency and building envelope insulation. In 2009, the Chinese Ministry of Housing and Urban-Rural Development (MOHURD) studied 44 households in residential buildings constructed during the 1980s in Shenyang, a city in northeastern China, and found that the average indoor temperature in heating-season was 14.7 °C. The North China energy-efficiency retrofit program aims to increase heating-season indoor temperatures as part of improving residential living conditions, a key concern of China's government.

During the 11th Five-Year Plan, the central government targeted energy-efficiency retrofits in $1.5 \times 10^8 \text{ m}^2$ of existing high-heating-consumption residential buildings in 15 provinces and municipalities. Although $1.5 \times 10^8 \text{ m}^2$ is a large figure, it represents only approximately 2% of the residential floor area in northern China, or roughly 2,500,000 apartments. It also represents less than 5% of the high-energy-consumption buildings that could benefit from energy-efficiency retrofits in that region. These numbers make clear that an efficiency retrofit program covering an even larger number of inefficient buildings will be needed in the future [20].

The North China energy-efficiency retrofit program was designed to reduce heating energy consumption and improve energy efficiency as part of achieving the energy-efficiency goals and emissions reductions of the 12th Five-Year Plan. However, the retrofit program has experienced many problems caused by a range of economic, social, and environmental factors, among which the most difficult have to do with the program's organization and financing. To tackle the financing problems, China's central and local governments implemented a retrofit subsidy policy during the 11th Five-Year Plan, which was intended to stimulate the retrofit market and attract social funding for retrofit projects.

Lu et al. [21] analyzed retrofit projects in China, Poland, and Germany and, based on that analysis, proposed financing mechanisms that might be applicable in China's northern heating region. Yin et al. [40] studied the current financing arrangements and mechanisms used in the North China energy-efficiency retrofit program using “strengths, weaknesses, opportunities, and threats”

(SWOT) analysis. This study proposed measures to stimulate consumer participation in the program. Based on retrofit experience elsewhere, Ding et al. [11] and Zhu and Wang [48] discussed feasible financing mechanisms and suggested approaches for future retrofit programs. Currently, in addition to traditional financing mechanisms, a number of new financing approaches have been used in the retrofit program, including energy performance contracting and incentives.

Energy performance contracting is effective for stimulating market-oriented operation of energy-efficiency retrofits [28]. Using the decision-making model for energy service companies (ESCOs), which was developed based on game theory, Zhang et al. [43] found that ESCOs can ensure maximum profits by applying advanced techniques and selecting appropriate clients.

Researchers also studied central and local government incentive policies for energy-efficiency retrofits [18,41,47]. Because the building energy-efficiency market depends heavily on government participation, it was proposed that the Chinese government increase its investment in retrofits and promulgate additional fiscal and tax incentive policies to support the retrofit program [17,32]. Zhao et al. [44] devised a method of calculating central government subsidies based on retrofit measures installed and resulting energy saved.

In recent years, the financial benefits that energy consumers receive from energy-efficiency retrofits have drawn researchers' attention. Amstalden et al. [2] analyzed the profitability of energy-efficiency retrofit investments in Switzerland's residential buildings from the home owner's perspective. That study showed that owners of retrofitted buildings obtain significant financial benefits when energy prices are high. Banfi et al. [4] evaluated investors' willingness to pay for energy-efficiency retrofits in Switzerland's residential buildings. Their experimental results suggest that investors place high value on financial benefits resulting from retrofits.

The purpose of this paper is to thoroughly analyze and explore the organizational model, financing mechanisms, and related issues in the North China energy-efficiency retrofit program. First, we define the target consumers and financing mechanisms and arrangements that have been used in the retrofit program to date, through an analysis of cases. Next, we summarize the main concerns surrounding investment in retrofits and financing of the program along with related problems and policy obstacles. Finally, we make recommendations for improving the program's success.

2. Retrofit measures and costs

The subsections below describe the primary retrofit measures that make up the North China energy-efficiency program and their costs.

2.1. Retrofit measures

The North China energy-efficiency program encompasses three types of retrofits, which are applied based on building type and energy consumption: installation of heat metering and temperature regulation of indoor heating systems; measures to balance the

heat source, pipeline, and central heating station; and measures to improve building envelope energy-efficiency [27]. The three types of retrofits are described in detail below.

- (1) **Heat metering and temperature regulation of indoor heating systems**
Feasible, cost-effective heating metering measures are to be chosen based on local conditions. The preferred option is metering of both the building's heat source and individual residential units [45]. Measures applied to indoor heating systems are intended to be determined based on the actual condition of the systems and to minimize residents' ability to interfere with the equipment. The target of energy efficiency for existing residential buildings can be achieved by heat metering and temperature regulation of indoor heating systems.
- (2) **Measures to balance heat source and pipeline**
The heat source retrofit plan is intended to be feasible both in terms of technologies applied and financial support. In addition to metering of the heat source, heating pipeline, and central heating station, measures include control devices for hydraulic equilibrium and frequency conversion. The measures applied to the boiler and heating station are supposed to be compatible with the indoor heating system.
- (3) **Building envelope energy-efficiency measures**
Building envelope energy-efficiency measures are applied to exterior walls, windows, doors, roof, floors, and other envelope elements as appropriate for the climate zone and type of structure. Preference is given to measures whose installation will cause minimum disturbance to the environment and to building residents. The post-retrofit building envelope heat-transfer coefficient and tightness are to meet the national energy-efficiency design standard.

2.2. Retrofit costs

Retrofit costs vary widely in northern China because of discrepancies in economic development among different regions.

The average retrofit costs are 47–60 Yuan/m² for heat source and pipeline efficiency measures and 140–184 Yuan/m² for building envelope measures [11]. Previous studies show that the average cost for heat metering and temperature regulation retrofits is approximately 30–40 Yuan/m². Therefore, overall, costs range between approximately 220 and 280 Yuan/m².

China central government implemented the policy of financial subsidy to support energy-efficiency retrofit by providing 6 Yuan/m² for the retrofit projects as the start-up fund. With the accomplishment of the retrofit, China central government checks the retrofit and evaluates energy-saving effect, then disburses the entire subsidy according to the regional standard of 45 Yuan/m² for cold region and 55 Yuan/m² for severe cold region [26].

3. Retrofit program participants

Seven stakeholders are involved in the North China energy-efficiency retrofit program:

- (1) **The central government** initiated and directs the program and is responsible for developing the overall program plan, assigning responsibility for retrofit tasks, designing economic incentive policies to support the program, and devising the evaluation method for the program.
- (2) **Local governments** at different levels execute energy-efficiency regulations and policies promulgated by the central

government and organize and implement the retrofit program locally. In addition to enforcing central government policies and regulations, local governments formulate supporting policies and work out specific implementation details appropriate to local conditions.

- (3) **Heating enterprises (HEs)** supply heat to buildings and benefit from the program in two ways: with heat metering, enterprises can charge building residents for actual energy consumption rather than on a floor-area basis as is traditionally done, and other retrofit measures enable suppliers to save heating costs and expand the area served. HEs also benefit from the heating pipeline fee and from new users added to the system. Thus, heating companies theoretically have incentive to invest in the program. However, investments by heating enterprises in program retrofit projects have been rare, for three reasons:
 - (a) Most HEs have limited funds available for such investments and cannot afford to pay for energy-efficiency retrofits without additional financing from other sources.
 - (b) Most HEs are not able to calculate the effect of energy-efficiency retrofits or the payback period for measures and therefore to understand the performance and financial risks involved in investing in efficiency measures.
 - (c) HEs are likely to earn less from charging consumers for actual metered energy use compared with what they earn from the current practice of charging users based on floor area. Therefore, HE profits are not likely to increase as a result of investing in retrofit projects.
- (4) **Property rights units (PRUs)** own residential properties and are usually state-owned enterprises. PRUs provide staff housing as a social benefit for their employees. Typical staff housing was built during the 1970s without building envelope insulation and thus is in need of retrofitting. One building is often shared by several PRUs, so coordination and communication among the units is required for a retrofit project to be implemented.
This feature of China's staff housing differs from conditions in former East Germany and Poland, whose financing mechanisms we studied for this analysis. Existing residential buildings in former East Germany were typically constructed by housing cooperatives and owned by the government [19]. Because a single entity occupies these buildings, and there has been very little housing privatization, energy-efficiency retrofits are simple to implement. In contrast, most housing in China has been sold to individuals as part of housing reform and is now privately owned. Because of the prevalence of private housing ownership of residential buildings in northern China is diverse; owners include governments, corporations, and residents. This diverse range of property owners often has difficulty agreeing on the allocation of retrofit profits, which creates a barrier to implementation of retrofits.
- (5) **Property management companies (PMCs)** oversee property for residential building owners. Management companies might bring together owners of existing buildings to co-finance and share the economic and social benefits of energy-efficiency retrofits.
- (6) **Residents** benefit directly from improvements in their living environment as a result of retrofit measures and the reduction of heating expenses resulting from metering of actual heat use. Residents' awareness of the retrofit program is the most important factor in their willingness to cooperate with and invest in retrofits.
- (7) **ESCOs** can negotiate contract energy management for HEs after retrofits are installed; in this role, ESCOs benefit from reductions in energy costs resulting from retrofits. The building energy efficiency market in China was more than 20 billion

Yuan by the year 2010, with an annual growth rate of more than 30% [30]. ESCOs are predicted to become the future financing agents for the North China energy-efficiency program.

Different retrofit program stakeholders play different roles and represent different interests, resulting in differences in awareness of and willingness to invest in retrofits.

Table 1 shows the issues of importance to different retrofit program stakeholders.

4. Financing and leadership

Large-scale implementation of the North China energy-efficiency retrofit program requires major financial support, which will need to come from various types of funding and funding arrangements.

We reviewed examples of financing mechanisms for large-scale retrofit programs in Germany, Poland, and the United States.

In Germany, where residential buildings typically have single owners, the federal and state governments have collaborated to implement an energy-efficiency retrofit program. The financing scheme in Germany has four elements: preferential 10- to 15-year loans with interest rates of 1–3%, investment by property owners or residents, commercial loans guaranteed by the state government, and special loans for specific energy-saving technologies (such as heat recovery and solar energy). Preferential loans must be for less than 75% of the total retrofit investment [21,37].

In Poland, retrofit program financing consists of loans from national building funds, through BGK bank, with 75% of loan interest rate in the duration of 7 years and investment by the property owners or residents. The total amount of funding from

the loan cannot be more than 80% of the project's cost [45]. In the U.S., financial incentives include subsidies from all levels of government and from public institutions as well as tax deductions and exemptions [36].

These examples from Germany, Poland, and the U.S. suggest that the financing mechanisms for large-scale residential retrofit programs in developed countries typically fall into three categories: government funding, whether in the form of direct funds or loan guarantees; government policies such as tax incentives, preferential loans, loans discounts, etc.; and investments by property owners or residents. Government policies have leveraged mature energy-efficiency retrofit markets in the example countries.

Funding of retrofits is the best guarantee of their implementation. The North China energy-efficiency program is in an early stage of development, and there is no mature market for energy-efficiency retrofits comparable to the markets in developed countries. In addition, retrofit funding is inadequate. The central government's subsidy policy advises that the retrofit funds should be raised by market mechanisms but gives no information regarding the means by which this is to take place.

MOHURD's detailed 2009 investigation of the energy-efficiency retrofit program in China's northern provinces is the source of the six cases in Table 2. For each case, we list the retrofit or combination of retrofits corresponding to the six types of funding arrangements currently in use in China. We group the cases according to the stakeholder primarily responsible for funding the project: local government, heating enterprise, property management company, property rights unit, ESCO, or a combination of stakeholders (CS). The financing arrangements shown in Table 2 could serve as models for designing funding mechanisms elsewhere in China.

The retrofit measures in the table are coded as follows: "A" indicates heat metering and indoor heating-system temperature

Table 1
Benefits, roles, funding, and barriers affecting stakeholders in residential energy-efficiency retrofits in North China.

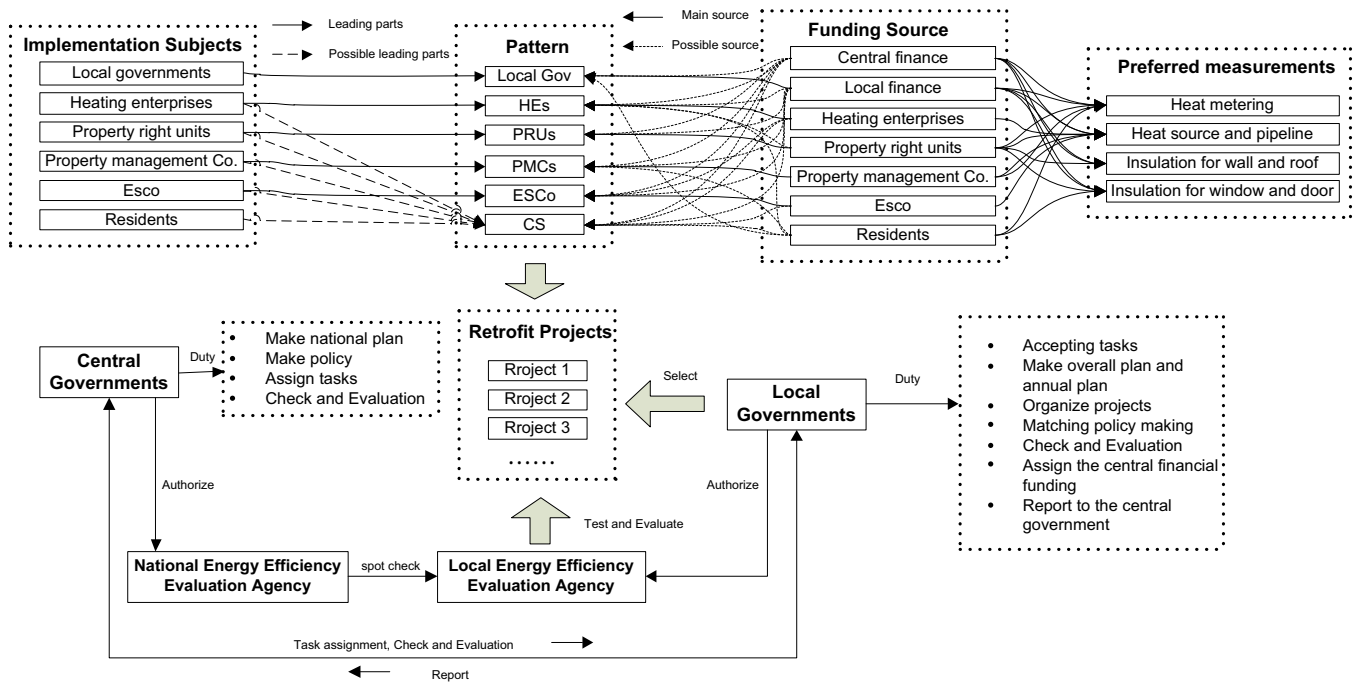
Stakeholder	Motivation or benefit	Role in implementing retrofit	Funding	Possible barriers
Central government	Achieving national energy-efficiency goal Improving people's living conditions	Assigning retrofit projects Making policy Verifying retrofits and evaluating performance	45 Yuan/m ² (floor area) for cold region or 55 Yuan/m ² for severe cold region, from central finance	Too many retrofit projects Subsidies not sustainable
Local government	Completing local energy efficiency projects Improving people's living conditions	Accepting assigned projects organization Implementing policy to match central government's Verifying and evaluating retrofits reporting	Unequal funding from local sources (maximum – 110 Yuan/m ² ; minimum – 0 Yuan/m ²)	Few matching funds Not paying enough attention
Heating enterprise	Reducing heating cost Completing task assigned by local government Increasing collection rate of consumer heating fees	Carrying out retrofit projects Investing in retrofit projects	Depends on retrofit projects and heating enterprise. Most enterprises have invested in balancing of heat source and pipeline	Insufficient motivation Lack of funds to invest
Property rights unit	Reducing heating costs Improving indoor thermal comfort	Carrying out retrofit projects Investing in retrofit projects	Most property right units invested in all types of retrofits	Insufficient motivation Lack of funds to invest
Property management company	Reducing heating expenses Improving indoor thermal comfort	Organizing property owners to co-finance	Most property management companies invested in all types of retrofits together with residents	Insufficient motivation
Residents	Reducing heating expenses Improving indoor thermal comfort Increasing property value	Cooperating in investing or carrying out retrofits Investing in retrofits	Most residents choose to invest in window retrofits	Unwillingness to cooperate in retrofits involving coordination of multiple residents

Table 2

Comparison of financing mechanisms for different types of retrofits in North China.

Retrofit types: A – heat metering and indoor heating system temperature regulation; B – heat source and pipeline balancing; C – building envelope energy-efficiency measures.

Case	Lead financing agent	Investors	Percentage funded	Retrofit type	Cost (Yuan/m ²)	Savings (kgce/m ² year)	Payback (years)
1	LG – government	Central and local government	100.0	C	200.0	11.30	18.1
2	HE – heating enterprise	Central and local government	33.3	A+B+C	60.0	3.00	20.4
		Heating enterprise	33.3				
		Residents	33.3				
3	PMC – property management company	Property management company	68.5	A+C	165.0	8.96	18.8
		Residents	31.5				
4	PRU – property rights unit	Central and local government	41.7	A+B+C	253.0	13.20	19.6
		Property rights unit	33.3				
		Residents	2.05				
5	ESC – ESCO	ESCO	100.0	A+B	21.7	7.20	3.1
6	CS – combination of stakeholders	Property rights unit	88.8	A+B+C	198.7	22.70	8.9
		ESCO	11.2				

**Fig. 1.** The operation mechanism and financing patterns of the north China energy-efficiency retrofit program.

regulation measures, “B” represents measures to balance the heat source and pipeline, and “C” denotes building envelope energy-efficiency measures. The payback period is calculated based on a conversion coefficient of raw coal to standard coal of 0.7143 kgce/kg and an average price of raw coal of 700 Yuan/ton.

The differences in cost for the same retrofit options in Table 2 result from differences in the type, price, and quality of various building energy-efficiency products.

Fig. 1 shows the operational and financing details of the North China energy-efficiency retrofit program, including the responsibilities of the central and local governments, other retrofit stakeholders, and the funding sources for each of the six financing schemes identified in Table 2.

5. Payback methods

Depending on their budgets and goals, different stakeholders might voluntarily invest in different retrofit measures. For

example, most HEs will invest in retrofits that reduce their costs rather than in measures that improve the residential environment. The primary concern of HEs is that the indoor temperature reaches the minimum required by the government. HEs benefit from retrofits that expand their service area to include additional buildings, which allows them to earn additional heating pipeline access fees and to bill additional users for heat. However, some HEs belong to the state and are administrated by the government. These enterprises typically do not consider the investment benefits and payback when the governments assign retrofit tasks to them. For these government-owned enterprises, retrofit investments are similar to investment by the government.

When ESCOs are the primary investors, they are typically concerned about cost and payback of retrofit measures. ESCOs are motivated to invest in low-cost retrofits such as cases 1 (building envelope measures) and 2 (heat metering and indoor temperature regulation, heat source and pipeline balancing, and building envelope measures) in Table 2, and measures that have shorter payback periods (5–10 years, according to Vine [13]). For

example, the payback period for case 5 in Table 2, where an ESCO is the lead funding agent, is approximately 3 years, the shortest among all the cases.

Governments, when investing in energy-efficiency measures, typically prioritize long-term energy savings and improvement of the residential environment rather than payback period. Local governments usually combine energy-efficiency retrofits with other urban construction projects, funded by monies designated for that purpose. In addition, local governments typically focus on improving the urban and residential environment, and their priorities including improving the energy efficiency of older buildings, without concern for the length of the payback period, e.g., case 1 in Table 2, which has an 18-year payback.

PMCs, PRUs, and residents also tend to be less concerned about payback periods. PMCs typically focus on improving the quality of their service, and PRUs invest to improve the quality of their buildings for the benefit of their employees. Residents are more interested in improving indoor thermal comfort and in increasing the value of their housing as the results of retrofit measures. These priorities explain why cases 3 and 4 in Table 2 are implemented despite their long payback periods. In these cases, residents share in the energy savings in the form of a reduction in their heating fees.

6. Retrofit priority

Retrofit programs in other countries give priority to specific types of efficiency and other measures.

In Germany, retrofits of existing residential buildings prioritize not only energy efficiency but also water efficiency. New technologies are often installed as part of retrofits including solar hot water, solar heating, and power generation as well as fresh air ventilation with heat recovery, which qualifies for special preferential loans [45].

In Poland, the retrofit program prioritizes measures to improve heat source efficiency and modernize the district heating network. Measures include installation of high-efficiency boilers, heat exchangers, and modernized controls for heating source retrofits; application of high-efficiency insulated pipeline, hydraulic balance equipment, and temperature compensators for heating network retrofits; and installation of indoor heating system metering and controls [19].

In Spain, the retrofit program emphasizes building envelope thermal performance and thermal energy efficiency of building equipment [35].

In contrast to retrofit programs in these developed countries, the North China residential energy-efficiency program is integrated in the sense that it encompasses all three types of retrofits described in Section 2.1. This integration is important because the three types of retrofits affect other's energy efficiency. For example, building envelope efficiency retrofits increase insulation and thus result in reduced demand for heating while increasing the efficiency of the heat source and pipeline ensures that the energy saved by the buildings will not be wasted by the pipeline. Similarly, if the heat source and pipeline receive efficiency retrofits but the building envelope does not, energy will still be wasted through the building envelope. Carrying out the three types of retrofits simultaneously maximizes the total energy savings.

A heat source and pipeline generally serves tens of thousands to hundreds of thousands of square meters of building area, so there is huge energy-saving potential in heat source and pipeline retrofits. Uneven temperatures in buildings result in wasted energy; high temperatures in some parts of a building prompt occupants to let cold air in to cool the rooms while very low temperatures in other parts of the building do not meet the

minimum indoor temperature required by the government. In this case, heating suppliers have to provide extra heat to ensure that the coldest portions of these buildings meet the government minimum temperature, which wastes significant energy, particularly when pipelines are inefficient and hydraulics are not balanced. This situation is very common in China's northern districts. Investors who are interested in profit will find retrofits of the heat source hydraulic balance and pipeline attractive because of low cost and relatively short payback periods compared to the cost and payback of building envelope improvements.

The cases we analyzed show that a cost of 200–250 Yuan/m² for the three types of retrofits together can save 10–20 kgce/m² of energy per year with a payback period of at least 15 years. The long payback period means that it will be difficult for the program to attract investments from the energy services market. However, the combination of retrofits A (heat metering and indoor heating temperature regulation) and B (heat source and pipeline balancing), as shown in case 5 in Table 2, only costs 21.7 Yuan/m², for energy savings of 7.2 kgce/m² per year with a payback period of three years. This combination of retrofits with its short payback period will be more attractive in an energy services market.

Under all types of financing mechanisms except government financing, residents voluntarily invest in building envelope insulation because this measure directly benefits residents by improving indoor thermal comfort. Policy makers should take this finding into account because residents' investments are a source of funds for the program.

7. Obstacles to retrofit financing

In this section, we analyze five obstacles to funding for the North China residential energy-efficiency retrofit program.

7.1. Government takes the lead in implementing the program, but other stakeholders are inactive

There is insufficient involvement from all stakeholders in the North China retrofit program. It is appropriate for government to play an organizational role and take the lead in energy-efficiency demonstration projects as well as guiding the formation of new energy-efficiency market mechanisms. However, other stakeholders cannot afford retrofit projects because of massive demand for retrofit funds and the high risk of retrofit investments; as a result, few ESCOs have demonstrated interest in energy-efficiency retrofit investments, and an energy-efficiency retrofit market is not developing. The government should cultivate the residential energy-efficiency retrofit market by stimulating market demand. In addition, the plans and policies of various government agencies need to be integrated and coordinated; three different Chinese ministries (Industry, Tourism, and Commerce) are involved in energy efficiency of buildings [35].

Retrofits of existing residential buildings face many problems related to funding, technology and stakeholder participation. One reason for the lack of market-based financing channels results is a failure of all stakeholders to work together. Meanwhile, energy-efficiency retrofit market funds are currently insufficient, so retrofits in many northern cities depend heavily on central and local government incentive funds.

7.2. Start-up funds and financial support from local governments are not sufficient

The bulk of central government funding for the North China residential energy-efficiency retrofit program is in the form of subsidies paid after retrofits are verified. Incentive funds are

calculated based on the area retrofitted and on post-retrofit performance. Because incentives are distributed after the fact, these funds cannot be used up front to pay for installation of efficiency measures, and only a small amount of up-front funding is offered by the government. Similarly, in Spain, the financial incentives are also assumed to be insufficient [35].

In all cases above stakeholders paid for retrofits. This represents a significant financial burden because government start-up funding for retrofits is only 6 Yuan/m² and, as noted above, most of the government subsidy is paid only after the fact. Lack of up-front funding is counter to the government guidance encouraging social funding of efficiency retrofits and makes it difficult to raise funds for retrofit projects from a wide range of sources. If the government changed its policy to allocate incentive funds at the start of a retrofit project rather than after the fact, this would have a significant positive effect on the pace and number of energy-efficiency retrofits installed.

Provinces where retrofit programs have been most successful, such as Inner Mongolia and Shanxi, ensure adequate funding by providing an additional subsidy in an amount equal to the subsidy paid by the central government. Provinces that do not offer additional local financial support guide retrofit subjects in investing in retrofits only by incentives fund from the central government only to increase the financing amount and the investment risk. As a result, market-based financing channels for energy-efficiency retrofits are extremely restricted in those locations.

7.3. Lack of agreement among potential financing recipients is a barrier to retrofit funding

Widespread housing privatization and diversified property ownership in northern China make it difficult to find groups of stakeholders with unified interests in relation to retrofits. In addition, differing lifestyles and consumption patterns mean that residents of a multi-family building might have difficulty agreeing on retrofits in which to invest for their building. The lack of groups of residents or property owners with unified interests makes it difficult to arrange financing for retrofit projects. Table 3 summarizes key barriers associated with different types of retrofit funding arrangements.

7.4. Heating system reform is incomplete and incentives based on energy savings have not been introduced

Heat metering retrofits, which are an important part of the North China retrofit program, have not yet been completed. Meanwhile, the heating charges that were developed under China's planned economy are still in place in parts of the region, and a two-part tariff has not yet been introduced. Instead, heating fees are still charged based on the floor area heated. Until heating charges are based on metered usage, the benefits of other energy-efficiency retrofits cannot be verified because, without metering, there is no way to determine how heating usage changes. In

addition, if their heating bills do not decrease after retrofits, residents have no incentive to invest in those retrofits. Even if residents do not pay for a heating system retrofit, the retrofit will be meaningless to them if their heating expenses remain unchanged because they continue to be based on floor area rather than actual usage.

7.5. The primacy of social and environmental rather than economic retrofit benefits hampers the development of an energy-efficiency market

Energy-efficiency retrofits provide more social and environmental than economic benefits. This is a key reason that governments must advocate and take the lead in retrofit programs; the economic benefits alone are insufficient to motivate other stakeholders to pursue retrofits. Moreover, when retrofits do not produce the expected return on investment, this creates a barrier to other capital entering the energy-efficiency market. Government incentives and other supportive policies are needed to encourage social capital to enter the energy-efficiency retrofit field. In other words, the fact that energy-efficiency retrofit measures have primarily social benefits restricts the diversity and flexibility of retrofit financing and is a barrier to implementation of the North China retrofit program.

8. Risk analysis

There are two key risks associated with the North China retrofit program. One is that the predicted energy savings might not be achieved, and the other is there is uncertainty about whether investors will receive their fair share of retrofit benefits.

Energy savings might not be achieved because many retrofit measures are relatively unsophisticated, for example, changing windows and installing heat insulation boards, and are undertaken by non-professionals without a pre-retrofit evaluation of the potential energy savings. Thus, it is difficult for investors to obtain a forecast of the potential energy savings from a retrofit measure before it is installed. The actual energy savings are important to the investor because the savings affect the payback period on the investment.

In the developed countries, mostly energy efficiency retrofit scenarios for existing residential buildings usually were modeled using the building performance simulation methods to forecast the retrofit effect. The simulation methods generally include EnergyPlus, IESve, eQUEST, DOE-2, ESP-r, BLAST, TRNSYS, TAS and so on [3,8,49]. The retrofit effect can be inclusive of indoor air condition, dynamic external envelope heat transfer, operational energy efficiency, occupant comfort, and mold growth potential [22]. Besides, before retrofitting buildings, a detailed economic analysis, for example life cycle cost method, was also adopted in experienced countries [16]. Based on the simulation methods and economic

Table 3
Key barriers associated with different funding arrangements.

Lead funding agent	Barrier
Local government HEs	Insufficient government funding to support large-scale retrofits needed in future Heating enterprises' lack of confidence in the effect that retrofits will have Heating enterprises failing to share with residents a portion of the profit from reduced energy use resulting from retrofit measures
PMCs PRUs	Property management company inability to broker an agreement with all residents Property rights units not receiving profit from retrofit
ESCO CS	Lack of an effective mechanism to guarantee that ESCOs receive payback from retrofit measures Lack of an effective mechanism guaranteeing that every investor receives payback from retrofit measures

analysis, the intelligent risk management strategy can be obtained in terms of the real local conditions.

Uncertainty about whether investors will receive their fair share of retrofit benefits applies especially when an HE and an ESCO invest together. Guaranteeing that the heating enterprise will give the ESCO a fair share of the payback is a key issue to resolve in promoting a retrofit market. In developed countries, the governments promote development of ESCo and guarantee fair benefit of ESCo through policies and law support, such as Model Energy Performance Contracting Legislation legislated by the United States government [14] and EU Code of Conduct for ESCOs established by European union [24]. Besides, insurers can participate in energy-efficiency retrofit to conduct the insurance and risk management, in order to guarantee the fair benefit share of ESCo [23].

Although the experienced countries have conducted well in avoiding the risks of energy-efficiency retrofit, emerging market countries probably have the same two problems compared with China. In Turkey, the government wants to establish the international ESCO market, but the lack of guarantee energy-saving effect and certain benefit return ways impede the market construction [1]. ESCO activities were recommended to be managed with risk-reducing methods like hedging instruments and venture capital to avoid the risks [25].

Therefore, establishing a guaranteed energy management contract arrangement could address this concern.

9. Benefit-sharing mechanism

The primary benefits that investors and residents receive from a retrofit are energy savings and improved indoor thermal comfort. Different stakeholders benefit in different ways. For example, if HEs and residents invest jointly in a retrofit, the HE benefits from reduced heating costs by sharing the benefit of the residents' reduced heating expenses. If PRUs or PMCs and residents jointly invest in a retrofit, they can share the reduced heating expenses while residents also enjoy improved indoor thermal comfort. If an ESCO and residents jointly invest in a retrofit, the ESCO will earn the profit margin between the heating expenses before and after the retrofit, and residents can also share in the reduced heating expenses along with enjoying improved indoor thermal comfort. Other combinations of investors and benefits are possible as long as the investor's benefits can be guaranteed.

In addition to benefiting from energy savings and improved thermal comfort, investors and residents can seek innovative sources of funding to compensate for retrofit costs. One way of earning additional funds is by expanding the residential space available in a retrofitted building and selling the new space. Methods of expanding the residential space include adding a new floor on top of a building, increasing balcony size, and developing the underground space below a building. Funds from selling these newly developed spaces can be shared among investors and residents. Another means of raising funds is transferring a portion of the mandatory building maintenance funding to retrofit investors. Maintenance funding comes from residents and is designated for improving their living spaces.

In the developed countries, because the market of energy-efficiency retrofit has matured, lots of energy-saving service enterprises have operated in the energy-efficiency retrofit market. They provide the professional services to achieve the energy-saving targets, so as to realize returns for themselves and heat comfort enhancement for building owners. Generally, ESCOs are the main force role in the energy-efficiency retrofit market through the sophisticated mechanisms of experienced countries, such as U.S., Canada, and European Union [29]. Within the term of

the agreement, most of benefits from energy saving belong to the ESCOs, and when the agreement finished, the energy saving benefits will return to the owners [13]. The prosperous and sound building energy efficiency law and economic environment have been created through energy efficiency standards and laws issued and energy efficiency subsidies and tax preference provided by the governments. The building owners should follow the standards and laws, and then the opportunity of energy efficiency benefits appear. The subsidies and tax preference can provide the financial support, and related policies and reasonable verification protocol such as International Performance Measurement and Verification Protocol (IPMVP) can guarantee ESCOs deserve the benefits and the building owners enjoy the better heat comfort. However, higher human cost in developed counties reduces the benefit of energy-efficiency retrofit [46]. The relative smaller wages for workmen can make the investors inclusive of building owners get more affordable and more profit in China.

Therefore, under referring the experience of development countries, one means of addressing concerns regarding equitable benefit-sharing would be for the government to design a template contract for building retrofit projects that specifies the arrangements for sharing benefits among residents and other investors, including how the payback for the measures is allocated.

10. Policy improvements

The subsections below describe recommendations for improving policies covering retrofit financing, stimulating the energy-efficiency retrofit market, and altering the method by which consumers are charged for heating.

Two key recommendations for improving retrofit financing are government involvement in researching and implementing financing mechanisms to meet varying local needs and in introducing incentives to ensure that investors will benefit economically from retrofits.

10.1. Strengthening financial support and promoting retrofit demonstrations

Central and local government incentives are key to promoting the North China retrofit program. For the program to succeed, all levels of government must focus on stimulating the energy-efficiency retrofit market, expanding the financing options, and encouraging stakeholders to invest in efficiency measures.

Local governments in northern China need to carefully analyze which retrofit models and financing arrangements are compatible with local realities. Energy-efficiency retrofits depend on government coordination and financial support; as noted above, it is difficult to mobilize stakeholders with differing interests to invest in retrofits. Government at all levels should develop financing mechanisms and retrofit schemes that are appropriate to local building and climate characteristics.

10.2. Changing the government's role in addressing barriers to retrofit funding

The government's role in the retrofit program should be to provide guidance and economic incentives to stimulate an energy-efficiency retrofit market and encourage stakeholders to save energy. Stakeholders will only invest in retrofits if the investment serves their interests. The government should introduce an economic incentive policy that levels the energy-efficiency retrofit market and is compatible with other retrofit measures and

policies. The retrofit experience in developed countries offers models of successful policies. For example, the German government worked with the German Investment Bank to provide preferential loans for retrofit projects, and the Polish government entrusted Poland's BGK Bank with the national building energy-efficiency retrofit fund for [19]. The Chinese government needs to promulgate fiscal and tax incentive policies that will reduce the differences among retrofit stakeholders' economic interests and will close the gap between the economic and social benefits of energy-efficiency retrofits.

10.3. Cultivating the energy-efficiency retrofit market

Four key strategies for cultivating the energy-efficiency market in North China are: targeting building envelope retrofits with government subsidies, making use of existing alternate funding sources to support retrofits, expanding the financial instruments available to support retrofits, and establishing quotas for heating energy consumption to stimulate participation of HEs in the retrofit program.

- (1) Offering incentives that target building envelope retrofits
Our analysis and case studies show that building envelope retrofits are costly and unlikely to attract investor funding whereas heat source, pipeline, and heat metering retrofits have the potential to attract funding in an energy services market. Therefore, we recommend that the government direct subsidies to building envelope retrofits and let the market elicit investments in heat metering and heat source/pipeline retrofits.
- (2) Exploiting existing financing channels
The central and local governments are currently the primary, stable sources of funding for retrofits. These funds are in the form of subsidies awarded based on energy savings and cover 15–20% of the total retrofit cost. Given the scale of the retrofits envisioned for the future, the central and local governments should create a special fund to support this effort. Additionally, maintenance funds, wall materials reform funds, and housing funds, most of which have not been used, can be tapped to pay for retrofits if the government expands the definition of the uses of those funds to include energy-efficiency retrofits. The government could also support the retrofit program with some of the proceeds from the auction of land for new building projects.
- (3) Improving China's incentive policy
Few financial instruments are currently available for the North China energy-efficiency retrofit program. Additional options that would support the program include low-interest and discount loans for retrofit investors and tax exemptions and credits for HEs and ESCOs.
- (4) Establishing heating energy consumption limits
One way to transform the energy-efficiency retrofit program from a voluntary to mandatory initiative that will stimulate an energy-efficiency market is to gradually impose heating energy consumption limits. Mandatory limits would give HEs strong incentive to invest in efficiency measures.

10.4. Expanding heating system reform and evaluating retrofit effects scientifically

The centerpiece of heating system reform is installation of heat metering and energy-efficiency retrofits in existing residential buildings in northern China. Currently, heating fees are based on the floor area heated, which gives consumers no incentive to save energy because bills based on floor area remain the same even if the consumer uses less heat. Therefore, heating

consumers have no motivation to invest in efficiency measures. Charging consumers based on actual heat energy consumption rather than floor area would create a strong motivation to install energy-saving measures. Billing based on actual usage should be implemented as soon as practically possible to stimulate the retrofit program.

Many uncontrollable factors influence the performance of efficiency retrofits. Uniform, objective criteria for evaluating retrofit performance are needed to reduce the risk of investing in efficiency measures. MOHURD has already promulgated two relevant policies: "methods for checking heat metering and energy-efficiency retrofits of existing residential buildings in northern China" and "an explanation of the accounting method for retrofit workload and energy savings in existing residential buildings." The relevant departments should further standardize the criteria for evaluating retrofit performance to encourage retrofit financing.

11. Conclusions

The North China residential energy-efficiency retrofit program is a long-term initiative. The following recommendations should be considered by the government and other parties involved in developing the efficiency retrofit market and technologies, and in organizing and managing aspects of the program:

- (1) Changing the nature of financial subsidies for retrofits. As noted in our analysis, low-cost retrofits (heat metering and pipeline measures) tend to consume the available government subsidies whereas those funds would be more effective supporting the high-cost retrofits (building envelope measures), in which HEs, ESCOs, and other non-governmental entities are reluctant to invest. Therefore, we recommend that central government financial subsidies be concentrated on supporting on high-cost retrofits (i.e., building envelope measures) only. Heat metering and heat source and pipeline measures are more likely to attract funding in the retrofit market because of their lower cost and greater cost-effectiveness.
- (2) Expanding government funding sources. Many underused building-related funds, such as the housing accumulation fund, housing maintenance fund, and wall material reform fund, could be used for energy-efficiency retrofits. Another way to expand funding for retrofits is to develop unused building spaces, such as underground areas or new upper floors. Funds from the sale of these spaces can be used as the payback for efficiency measures. Government policies should be developed to regulate the use of such funding sources.
- (3) Disseminating examples of successful financing and opening a dialog with stakeholders to develop additional funding mechanisms. The government can take the lead in disseminating examples of successful financing strategies as models to enable stakeholders to develop their own locally appropriate financing mechanisms. The government and stakeholders can work together to devise additional financing mechanisms and develop a market for energy-efficiency retrofits.
- (4) Developing policies governing energy-efficiency market participation. The government's primary role should be to provide policy guidance for the retrofit program as well as economic incentives to stimulate an energy-efficiency retrofit market. After establishing policies to help get the market off the ground, the government should gradually withdraw and allow the market to drive retrofit installations. The government should regulate the market by means of mandates regarding

qualified energy service companies, service contracts, energy savings measurement, investment risk, etc.

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